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Review

On the use of small and cheaper sensors and devices for indicative citizen-based monitoring of respirable particulate matter☆

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ABSTRACT

Respirable particulate matter present in outdoor and indoor environments is a health hazard. The particle concentrations can quickly change, with steep gradients on short temporal and spatial scales, and their chemical composition and physical properties vary considerably. Existing networks of aerosol particle measurements consist of limited number of monitoring stations, and mostly aim at assessment of compliance with air quality legislation regulating mass of particles of varying sizes. These networks can now be supplemented using small portable devices with low-cost sensors for assessment of particle mass that may provide higher temporal and spatial resolution if we understand the capabilities and characteristics of the data they provide. This paper overviews typical currently available devices and their characteristics. In addition it is presented original results of measurement and modelling in the aim of one low-cost PM monitor validation.

1. Introduction

It has been well established through a number of epidemiological studies that respirable particulate matter (RPM) may act as a health hazard causing respiratory mortality and morbidity (Pope and Dockery, 2006). High temporal and spatial resolution is an imperative to obtain reliable data that could be used to setup policies and measures that would protect the health of the citizens. Compliance monitoring networks that are currently in use consist of a limited number of stations using standardized QA/QC protocols. These reference and equivalent ambient PM and gaseous monitoring units do not capture spatial gradients in the areas for which they are representative, and cannot provide individualized personal information. For monitoring indicative levels of the ambient RPM, at a much higher spatial resolution, a network of small and cheap sensors could represent an alternative opportunity. If appropriate infrastructure is in place these sensor networks have the potential to offer unique opportunity for citizen-participatory sensing. A portable computing devices such as a smartphone or a tablet computer can be used to form interactive, participatory sensor networks that could facilitate public and professional users to jointly collect, analyse and share a wide range of different data (Burke et al., 2006). The true potential of such data gathering has not yet been established, but a number of studies are underway that will provide information about this issue (Snyder et al., 2013; Kumar et al., 2015; Seto et al., 2014).

The purpose of citizen-based monitoring is to assess location-specific (static or mobile use) or personal-specific indicative levels of PM employing a large number of devices that give people the ability to monitor the air they breathe (Autsen, 2015). One of the most important issues is comparability, or variability of response between the devices. Currently, procedures that would help establish and ensure comparability in larger scale deployments of such devices do not exist. This limits the potential use of the information the devices may provide.

Monitoring networks are subject to strict quality control and assurance that allows comparability across instruments and

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networks. By analogy, prior to using low cost RPM sensors, their characteristics need also to be assessed. Information needs to be acquired about various parameters such as: (a) detection limit, (b) concentration range, (c) temperature range, (d) influence of humidity, (e) stability of response – comparability and variability between individual sensor devices (f) sensitivity to detect temporal variation (g) concentration differences and calibration factor between sensor device and reference PM monitor. It may be necessary to perform complex procedures of calibration checks prior to deployment. A first step is to understand the capabilities of the sensor devices, and characteristics of the information they provide.

This paper gives an overview of available cheap miniature RPM sensors and devices that offer indicative information about RPM. They are currently either fully commercially available or in a late development phase. Furthermore, an analysis of sensors characteristics is presented, in particular with respect to the limit of detection relevant to the current EU legislative (2008) and WHO (2005) guidelines regarding the levels of particulate matter in ambient air. While it is currently not likely that sensors are providing information that can be used in relation to this legislation, it provides useful indication of ranges the devices should cover.

2. Paticulate matter standards and existing monitoring

For characterization of PM in ambient air there are a number of important properties that should be taken into account, including (i) total mass concentration of selected fractions of particulate matter, (ii) particles number concentration, (iii) particles size distribution, (iv) daily variations of concentrations, peak values (v) chemical composition. Currently, the most common health relevant metric is mass related to particle size, and expressed as Total Suspended Particles (TSP), particulate matter smaller than 10 μm or PM_{10} and smaller than 2.5 μm or $PM_{2.5}$. It is thus convenient to require that the range of particulate matter mass to be determined by the devices has to cover ranges related to the legislation (set to protect human health), and to the ambient concentration levels, and should be related to a common metric for particulate matter. PM limits and targets for 24 h and annual averages significantly differ from country to country, reflective to some extent of the strength of natural and anthropogenic sources of PM at regional and country level. This is illustrated in Table 1 that provides examples of PM standards and objectives in selected counties around the world.

Table 1
Standards and objective for PM monitoring in urban area in selected counties all over the world (EU, 2008; WHO, 2005; US EPA, 2012; Ministry of Environment, Australian Government, 2005; Norma Official Mexicana, 2014; Brasil, 1990; Ministry of the Environment, Government of Japan, 2009; Ministry of the Environmental Protection of the People's Republic of China,2012; India Environmental Portal, 2009; Ministry of Natural Resources and Environment of Thailand, 2010; Federal Environmental Agency UAR, 2006).

Country	PM fraction	Guideline/standard (μg/m^3)	Averaging time	Statistics to be used; comment
WHO	PM_{10}	20	Annual	
		50	24-h	
	$PM_{2.5}$	10	Annual	
		25	24-h	
EU	PM_{10}	40	Annual	
		50	24-h	Not to be exceeded more than 35 times a calendar year
	$PM_{2.5}$	25/20	Annual	Target value/limit value after 2015 and 2020
US	PM_{10}	150	24-h	Not to be exceeded more than once per year on average over 3 years
	$PM_{2.5}$	12	Annual	Annual mean, averaged over 3 years
		35	24-h	98th percentile, averaged over 3 years
Australia	PM_{10}	50	24-h	Not to be exceeded more than 5 days per year
	$PM_{2.5}$	8	Annual	
		25	24-h	
Mexico	PM_{10}	75	24-h	
		40	Annual	Annual mean
	$PM_{2.5}$	45	24-h	
		12	Annual	Annual mean
Brazil	TSP	240/150	24-h	Not to be exceeded more than once per year
		80/60	Annual	Geometric mean
	PM_{10}	150	24-h	Not to be exceeded more than once per year
		50	Annual	Geometric mean
Japan	PM_{10}	200	24-h	98th percentile over 1 year
		100	Annual	
	$PM_{2.5}$	35	24-h	98th percentile over 1 year
		15	Annual	
China	TSP	300	24-h	
		200	Annual	
	PM_{10}	150	24-h	
		70	Annual	
	$PM_{2.5}$	75	24-h	
		35	Annual	
India	PM_{10}	100	24-h	
		60	Annual	
	$PM_{2.5}$	60	24-h	
		40	Annual	
Thailand	PM_{100}	330	24-h	
		100	Annual	
	PM_{10}	120	24-h	
		50	Annual	
	$PM_{2.5}$	50	24-h	
		25	Annual	
United Arabic Emirates	TSP	230	24-h	
		90	Annual	
	PM_{10}	150	24-h	